

## Chapter 9 – Biofiltration Treatment Facilities

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*Note: Figures in Chapter 9 are courtesy of King County, except as noted*

This Chapter addresses five Best Management Practices (BMPs) that are classified as biofiltration treatment facilities:

Biofilters are vegetated treatment systems (typically grass) that remove pollutants by means of sedimentation, filtration, soil sorption, and/or plant uptake. They are typically configured as swales or flat filter strips.

### 9.1 Purpose

The BMPs discussed in this Chapter are designed to remove low concentrations and quantities of total suspended solids (TSS), heavy metals, petroleum hydrocarbons, and/or nutrients from stormwater.

### 9.2 Applications

A biofilter can be used as a basic treatment BMP for contaminated stormwater runoff from roadways, driveways, parking lots, and highly impervious ultra-urban areas or as the first stage of a treatment train. In cases where hydrocarbons, high TSS, or debris would be present in the runoff, such as high-use sites, a pretreatment system for those components would be necessary. Off-line location is preferred to avoid flattening vegetation and the erosive effects of high flows. Biofilters should be considered in retrofit situations where appropriate. (Center for Watershed Protection, 1998))

### 9.3 Site Suitability

The following factors must be considered for determining site suitability:

- Target pollutants are amenable to biofilter treatment
- Accessibility for Operation and Maintenance
- Suitable growth environment; (soil, etc.) for the vegetation
- Adequate siting for a pre-treatment facility if high petroleum hydrocarbon levels (oil/grease) or high TSS loads could impair treatment capacity or efficiency
- If the biofilter can be impacted by snowmelts and ice, refer to Caraco and Claytor for additional design criteria (USEPA, 1997).

### 9.4 Best Management Practices

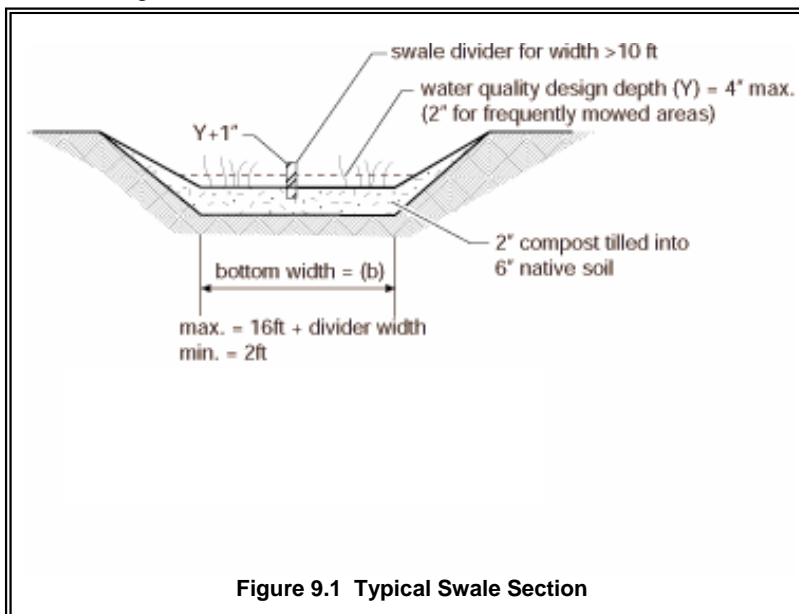
The following five Biofiltration Treatment Facilities BMPs are discussed in this Chapter:

BMP T9.10 – Basic Biofiltration Swale  
BMP T9.20 - Wet Biofiltration Swale  
BMP T9.30 – Continuous Inflow Biofiltration Swale  
BMP T9.40 – Basic Filter Strip  
BMP T9.50 – Narrow Area Filter Strip

## BMP T9.10 Basic Biofiltration Swale

### Description:

Biofiltration swales are typically shaped as a trapezoid or a parabola as shown in Figure 9.1.



### Limitations:

Data suggest that the performance of biofiltration swales is highly variable from storm to storm. It is therefore recommended that treatment methods providing more consistent performance, such as sand filters and wet ponds, be considered first. Swales downstream of devices of equal or greater effectiveness can convey runoff but should not be expected to offer a treatment benefit. (Horner, 2000)

### Design Criteria:

- Design criteria are specified in Table 9.1. A 229 minute hydraulic residence time is used at a multiple of the peak 15 minute Water Quality Design Flow Rate (Q) representing 91% runoff volume as determined by the Western Washington Hydrology Model (WWHM). (See Volume I)
- Check the hydraulic capacity/stability for inflows greater than design flows. Bypass high flows, or control release rates into the biofilter, if necessary.

- Install level spreaders (min. 1-inch gravel) at the head and every 50 feet in swales of  $\geq 4$  feet width. Include sediment cleanouts (weir, settling basin, or equivalent) at the head of the biofilter as needed.
- Use energy dissipators (riprap) for increased downslopes.

**Guidance for Bypassing Off-line Facilities:** *Most biofiltration swales are currently designed to be on-line facilities. However, an off-line design is possible.* Swales designed in an off-line mode *should not engage a bypass until the flow rate exceeds a value determined by multiplying  $Q$ , the off-line water quality design flow rate predicted by the WWHM, by the ratio determined in Figure 9.5b. This modified design flow rate is an estimate of the design flow rate determined by using SBUH procedures. Ecology's intent is to maintain recent biofiltration sizing recommendations (9 minutes detention at the peak design flow rate estimated by SBUH for a 6-month, 24-hour storm with a Type IA rainfall distribution) until more definitive information is collected concerning bioswale performance. The only advantage of designing a swale to be off-line is that the stability check, which may make the swale larger, is not necessary.* ~~using the new water quality design flow rate and hydraulic residence time are allowed to bypass stormwater at a lower flow rate than allowed in the 1992 manual. Ecology does not know if this will increase or decrease the annual average pollutant removal because no definitive information is known concerning the performance of properly designed swales at flow rates between the new water quality design flow rate and the old water quality design flow rate. Until such information is available, the determination of when to initiate bypass is left to the discretion of the local governments. If a local government chooses to retain the requirement to initiate bypass at the old water quality design flow rate, that flow rate is approximately 2.5 times the new water quality design flow rate. A flow splitter would be designed to initiate bypass at 2.5 times the new water quality design flow rate rather than at the new flow rate. Swales with such higher bypass rates should still be sized using the new approach in this manual.~~

*Ecology encourages comment concerning whether basic biofiltration swales should be allowed as off-line facilities. Should design and construction of flow splitting devices (intended to bypass flows above the off-line water quality design flow rate) be allowed upstream of the swale?*

### ***Sizing Procedure for Biofiltration Swales***

This guide provides biofilter swale design procedures in full detail, along with examples.

#### **Preliminary Steps (P)**

**P-1** Determine the Water Quality design flow rate (Q) in 15-minute time-steps using the WWHM. *Use the correct flow rate, off-line or on-line, for your design situation. Until the WWHM provides that information directly, estimate the water quality design flow rate using the 2-year return frequency flow predicted by the WWHM and Table 4.1.*

**P-2** Establish the longitudinal slope of the proposed biofilter.

**P-3** Select a vegetation cover suitable for the site. Refer to Tables 9.2, 9.3, 9.4, and 9.5 (in text) to select vegetation for western Washington.

#### ***Design Calculations for Biofiltration Swale***

There are a number of ways of applying the design procedure introduced by Chow (Chow, 1959). These variations depend on the order in which steps are performed, what constants are established at the beginning of the process and which ones are calculated, and what values are assigned to the variables selected initially.

The procedure recommended here is an adaptation appropriate for biofiltration applications of the type being installed in the Puget Sound region. This procedure reverses Chow's order, designing first for capacity and then for stability. The capacity analysis emphasizes the promotion of biofiltration, rather than transporting flow with the greatest possible hydraulic efficiency. Therefore, it is based on criteria that promote sedimentation, filtration, and other pollutant removal mechanisms. Because these criteria include a lower maximum velocity than permitted for stability, the biofilter dimensions usually do not have to be modified after a stability check.

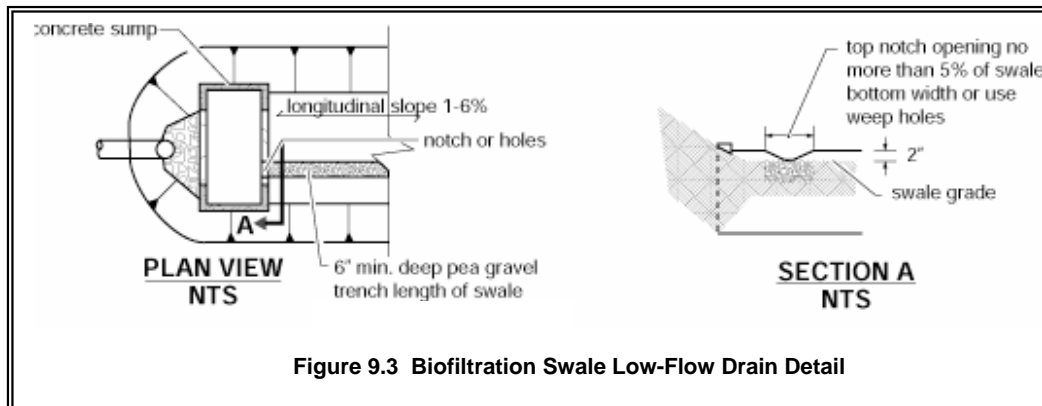
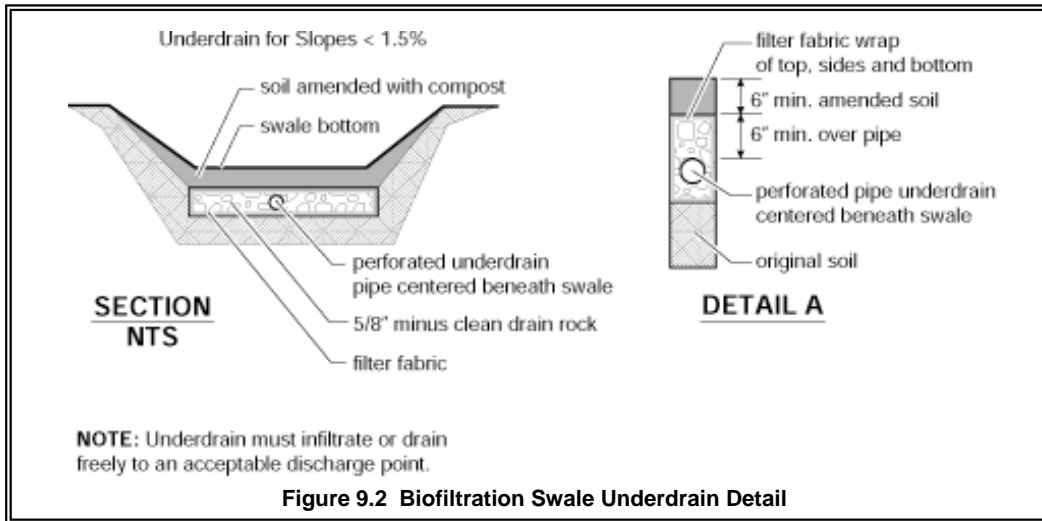
#### **Design Steps (D):**

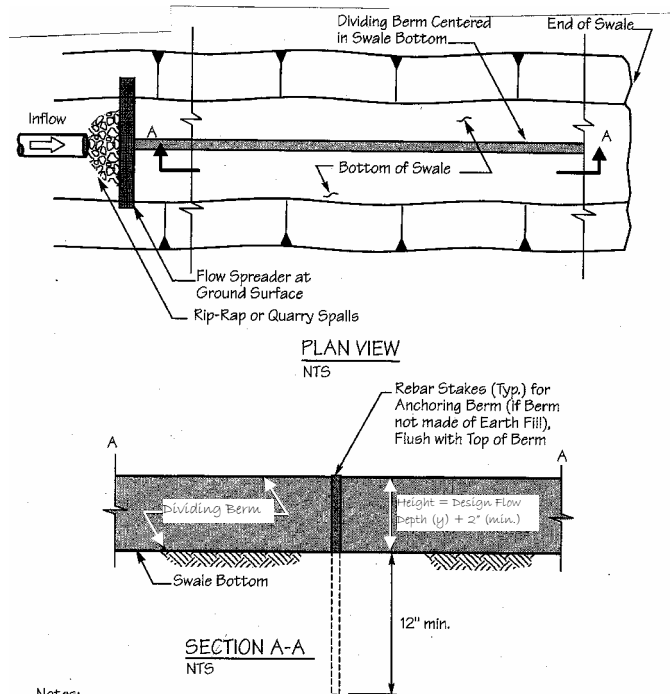
**D-1.** Select the type of vegetation, and design depth of flow (based on frequency of mowing and type of vegetation). (Table 9.1)

**D-2.** Select a value of Manning's n (Table 9.1 with footnote #3).

Table 9.1 – Sizing Criteria		
Design parameter	BMP T 9.10-Biofiltration swale	BMP T 9.40-Filter strip
Longitudinal Slope	0.015 - 0.025 <sup>1</sup>	0.01 - 0.15
Maximum velocity	1 ft / sec ( @ <i>K multiplied by the</i> WQ design flow rate ; for stability, 5ft/sec max. preferred (see also Table 9.3)	0.5 ft / sec
Maximum water depth <sup>2</sup>	2"- if mowed frequently; 4" if mowed infrequently	1-inch max.
Manning coefficient (22)	(0.2 – 0.3) <sup>3</sup> (0.24 if mowed infrequently)	0.35 (0.45 if mowed to maintain grass height ≤ 4")
Bed width (bottom)	(2 - 10 ft) <sup>4</sup>	---
Freeboard height	0.5 ft	---
Minimum hydraulic residence time at Water Quality Design Flow Rate	229 minutes ( <del>44</del> 18 minutes for continuous inflow) (See Volume I, Appendix B)	229 minutes
Minimum length	100 ft	Sufficient to achieve hydraulic residence time in the filter strip
Maximum sideslope	3 H : 1 V 4H:1V preferred	Inlet edge ≥ 1" lower than contributing paved area
Max. tributary drainage flowpath	---	150 feet
Max. longitudinal slope of contributing area	---	0.05 (steeper than 0.05 need upslope flow spreading and energy dissipation)
Max. lateral slope of contributing area	---	0.02 (at the edge of the strip inlet)

1. For swales, if the slope is less than 1.5% install an underdrain using a perforated pipe, or equivalent. Amend the soil if necessary to allow effective percolation of water to the underdrain. Install the low-flow drain 6" deep in the soil. Slopes greater than 2.5% need check dams (riprap) at vertical drops of 12-15 inches. Underdrains can be made of 6 inch Schedule 40 PVC perforated pipe with 6" of drain gravel on the pipe. The gravel and pipe must be enclosed by geotextile fabric. (See Figures 9.2 and 9.3)
2. Below the design water depth install an erosion control blanket, at least 4" of topsoil, and the selected biofiltration mix. Above the water line use a straw mulch or sod.
3. This range of Manning's n can be used in the equation;  $b = Qn/1.49y^{(1.67)}s^{(0.5)} - Zy$  with wider bottom width b, and lower depth, y, at the same flow. This provides the designer with the option of varying the bottom width of the swale depending on space limitations. Designing at the higher n within this range at the same flow decreases the hydraulic design depth, thus placing the pollutants in closer contact with the vegetation and the soil.
4. For swale widths up to 16 feet the cross-section can be divided with a berm (concrete, plastic, compacted earthfill) using a flow spreader at the inlet (Figure 9.4)





**Notes:**

1. Berm may be Made of Compacted Earthfill (seeded with grass), Timber, Concrete, Plastic, or Similar Weather - Resistant Non - Erodible Material.
2. Rebar Stakes or Similar Berm Anchoring Materials Needed if Berm Made of Timber, Plastic, or Concrete Curbing - Stake Placement Required at Both Ends of Each Individual Member (at a minimum).

**Figure 9.4 Swale Dividing Berm**

**D-3.** Select swale shape-typically trapezoidal or parabolic.

**D-4.** Use Manning's equation and first approximations relating hydraulic radius and dimensions for the selected swale shape to obtain a working value of a biofilter width dimension:

$$Q = \frac{1.49AR^{0.67}S^{0.5}}{n} \quad (1)$$

$$A_{\text{rectangle}} = Ty \quad (2)$$

$$R_{\text{rectangle}} = \frac{Ty}{T + 2y} \quad (3)$$

Where:

- Q = Water Quality Design flow rate in 15-minute time steps based on WWHM, (ft<sup>3</sup>/s, cfs) ([See Appendix I-B, Volume I](#))
- n = Manning's n (dimensionless)
- s = Longitudinal slope as a ratio of vertical rise/horizontal run (dimensionless)
- A = Cross-sectional area (ft<sup>2</sup>)
- R = Hydraulic radius (ft)
- T = top width of trapezoid or width of a rectangle (ft)
- y = depth of flow (ft)
- b = bottom width of trapezoid (ft)

If equations 2 and 3 are substituted into equation 1 and solved for T, complex equations result that are difficult to solve manually. However, approximate solutions can be found by recognizing that  $T \gg y$  and  $Z^2 \gg 1$ , and that certain terms are nearly negligible. The approximation solutions for rectangular and trapezoidal shapes are:

$$R_{\text{rectangle}} \approx y, \quad R_{\text{trapezoid}} \approx y, \quad R_{\text{parabolic}} \approx 0.67y, \quad R_v \approx 0.5y$$

Substitute  $R_{\text{trapezoid}}$  and  $A_{\text{trapezoid}} = by + Zy^2$  into Equation 1, and solve for the bottom width b (trapezoidal swale):

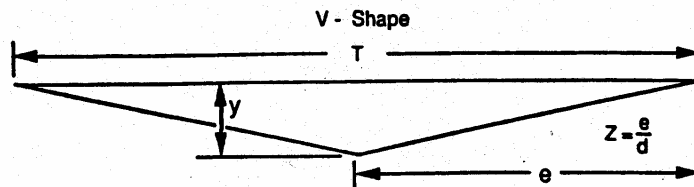
$$b \approx \frac{2.5Qn}{1.49y^{1.67}s^{0.5}} - Zy$$

For a trapezoid, select a side slope Z of at least 3. Compute b and then top width T, where  $T = b + 2yZ$ . (*Note: Adjustment factor of 2.5 accounts for the differential between Water Quality design flow rate and the SBUH design flow. This equation is used to estimate an initial cross-sectional area. It does not affect the overall biofiltration swale size.*)

If b for a swale is greater than 10 ft, either investigate how Q can be reduced, divide the flow by installing a low berm, or arbitrarily set b = 10 ft and continue with the analysis. For other swale shapes refer to Fig. 9.5.

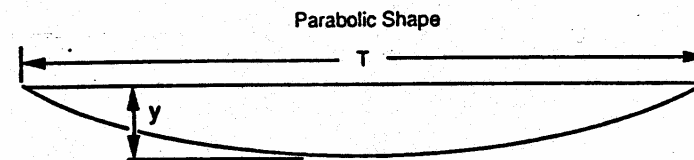


### CHANNEL GEOMETRY



Cross-Sectional Area (A) =  $zy^2$   
 Top Width (T) =  $2yZ$

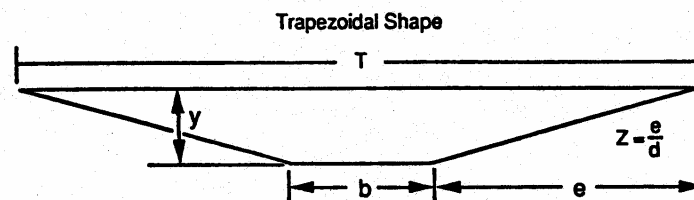
Hydraulic Radius (R) =  $\frac{zy}{2\sqrt{Z^2 + 1}}$



Cross-Sectional Area (A) =  $\frac{2}{3}Ty$

Top Width (T) =  $\frac{1.5A}{y}$

Hydraulic Radius (R) =  $\frac{T^2y}{1.5T^2 + 4y^2}$



Cross-Sectional Area (A) =  $by + Zy^2$   
 Top Width (T) =  $b + 2yz$

Hydraulic Radius (R) =  $\frac{by + Zy^2}{b + 2y\sqrt{Z^2 + 1}}$

Figure 9.5 Geometric Formulas for Common Swale Shapes

Source: Livingston, et al, 1984

**D-5. Compute A:**

$$A_{\text{rectangle}} = Ty \quad \text{or} \quad A_{\text{trapezoid}} = by + Zy^2$$

$$A_{\text{filter strip}} = Ty$$

**D-6. Compute the flow velocity at design flow rate:**

$$V = K \frac{Q}{A} \quad \text{or} \quad V = \frac{Q}{A}$$

*K = A ratio of the water quality design flow rate estimated using SBUH to the water quality design flow rate estimated using the WWHM. The value of K is determined from Figure 9.5a for on-line facilities, or Figure 9.5b for off-line facilities.*

If  $V > 1.0$  ft/sec (or  $V > 0.5$  ft/sec for a filter strip), repeat steps D-1 to D-6 until the condition is met. A velocity greater than 1.0 ft/sec was found to flatten grasses, thus reducing filtration. A velocity lower than this maximum value will allow a 229-minute hydraulic residence time criterion in a shorter biofilter. If the value of V suggests that a longer biofilter will be needed than space permits, investigate how Q can be reduced (*e.g., use of low impact development BMP's*), or increase y and/or T (up to the allowable maximum values) and repeat the analysis.

**D-7. Compute the swale length (L, ft)**

$$L = Vt \text{ (60 sec/min)}$$

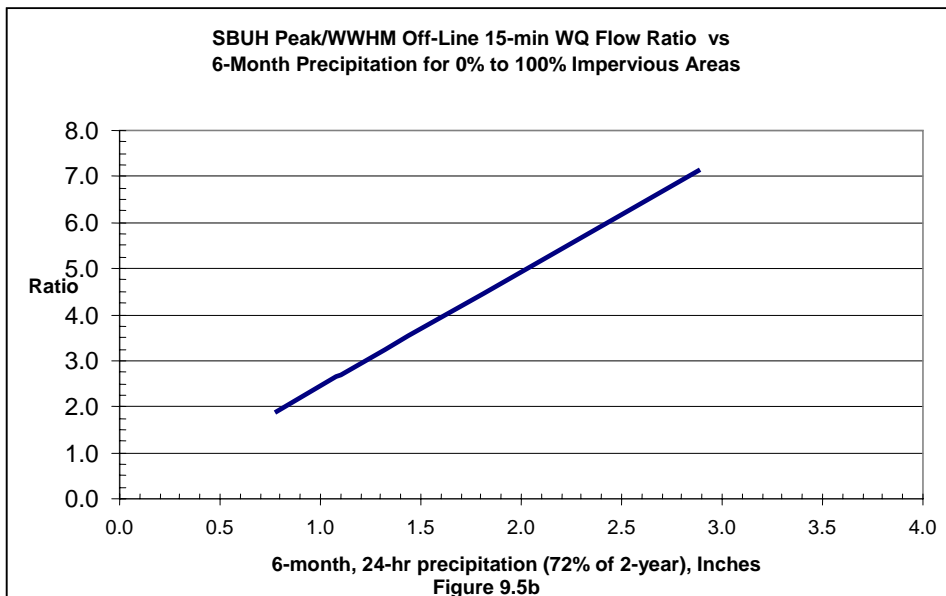
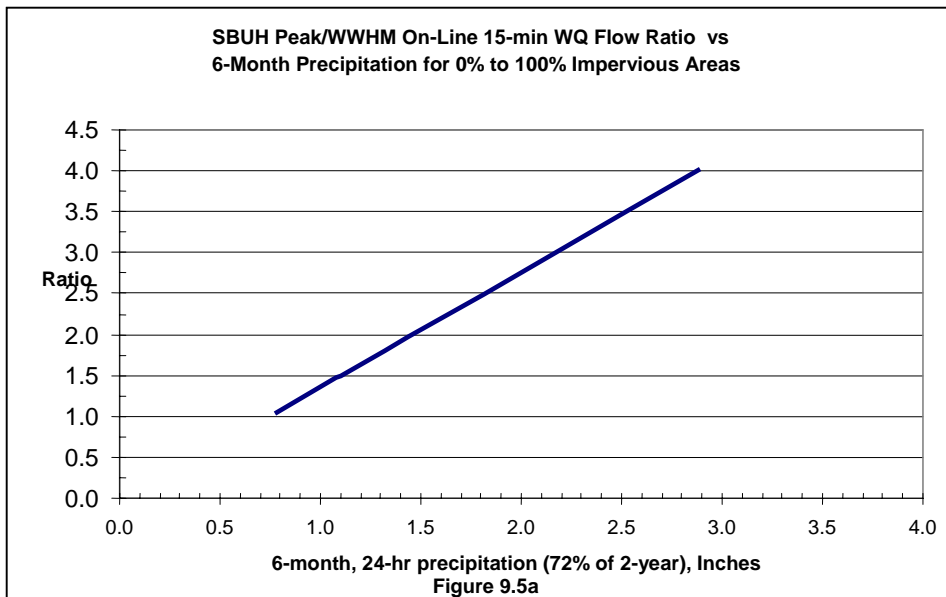
Where: t = hydraulic residence time (min)

Use t = 229 minutes for this calculation (use t = 44/8 minutes for a continuous inflow biofiltration swale). If a biofilter length is greater than the space permits, follow the advice in step D-6.

If a length less than 100 feet results from this analysis, increase it to 100 feet, the minimum allowed. In this case, it may be possible to save some space in width and still meet all criteria. This possibility can be checked by computing V in the 100 ft biofilter for t = 229 minutes, recalculating A (if  $V < 1.0$  ft/sec) and recalculating T.

**D-8.** If there is still not sufficient space for the biofilter, the local government and the project proponent should consider the following solutions (listed in order of preference):

- 1) Divide the site drainage to flow to multiple biofilters.
- 2) Use infiltration to provide lower discharge rates to the biofilter (only if the criteria and Site Suitability Criteria in Chapter 7 are met).
- 3) Increase vegetation height and design depth of flow (note: the design must ensure that vegetation remains standing during design flow).



- 4) Reduce the developed surface area to gain space for biofiltration.
- 5) Increase the longitudinal slope.
- 6) Increase the side slopes.
- 7) Nest the biofilter within or around another BMP.

### Check for Stability (Minimizing Erosion)

The stability check must be performed for the combination of highest expected flow and least vegetation coverage and height. A check is not required for biofiltration swales that are located "off-line" from the primary conveyance/detention system, ~~i.e., when flows in excess of the water quality design flow rate bypass the biofilter. Off line is the desired configuration.~~

Maintain the same units as in the biofiltration capacity analysis.

**SC-1.** ~~Unless runoff at rates at higher than the water quality design flow rate (or at rates higher than 2.5x the water quality design flow rate as an alternative allowed in this guidance) will bypass the biofilter, p~~Perform the stability check for the 100-year, return frequency flow using 15-minute time steps using an approved continuous runoff model. Until WWHM peak flow rates in 15-minute time steps are available the designer can use the WWHM 100-yr. hourly peak flows times an adjustment factor of 1.6 to approximate peak flows in 15-minute time steps.

**SC-2.** Estimate the vegetation coverage ("good" or "fair") and height on the first occasion that the biofilter will receive flow, or whenever the coverage and height will be least. Avoid flow introduction during the vegetation establishment period by timing planting or bypassing.

**SC-3.** Estimate the degree of retardance from Table 9.2. When uncertain, be conservative by selecting a relatively low degree.

Establish the maximum permissible velocity for erosion prevention (Vmax) from Table 9.3.

#### Stability Check Steps (SC)

Table 9.2 -- Guide for Selecting Degree of Retardance <sup>(a)</sup>		
Coverage	Average Grass Height (inches)	Degree of Retardance
<b>Good</b>	<2	E. Very Low
	2-6	D. Low
	6-10	C. Moderate
	11-24	B. High
	>30	A. Very High
<b>Fair</b>	<2	E. Very Low
	2-6	D. Low
	6-10	D. Low
	11-24	C. Moderate
	>30	B. High

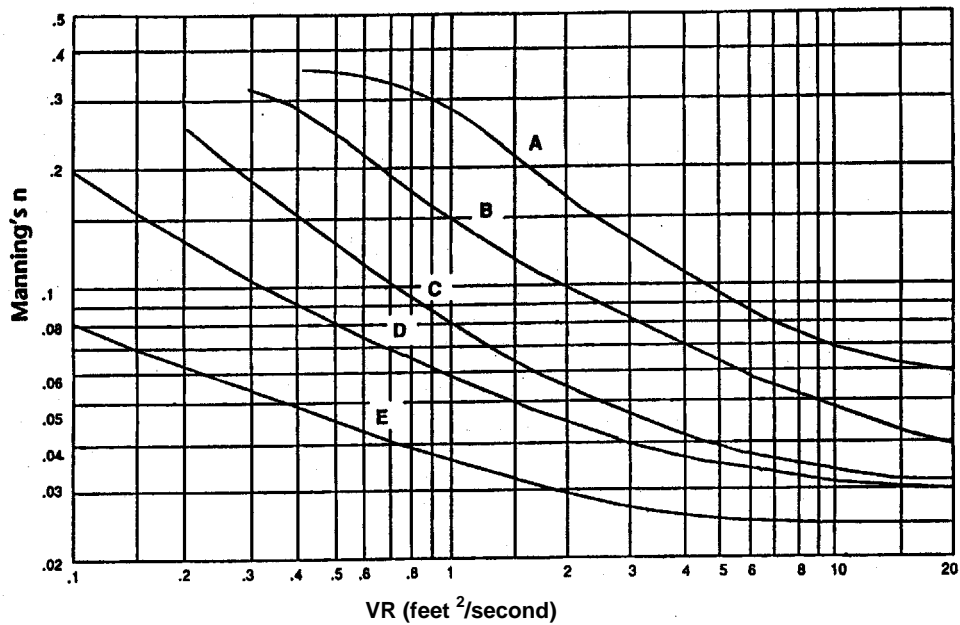
See Chow (1959).. In addition, Chow recommended selection of retardance C for a grass-legume mixture 6-8 inches high and D for a mixture 4-5 inches high. No retardance recommendations have appeared for emergent wetland species. Therefore, judgment must be used. Since these species generally grow less densely than grasses, using a "fair" coverage would be a reasonable approach.

Table 9.3 -- Guide for Selecting Maximum Permissible Swale Velocities for Stability*			
Cover	Slope (percent)	Maximum Velocity (feet per second [m/s])	
		Erosion-Resistant Soils	Easily Eroded Soils
Kentucky bluegrass Tall fescue	0-5	6 [1.8]	5 [1.5]
Kentucky bluegrass Ryegrasses Western wheat-grass	5-10	5 [1.5]	4 [1.2]
Grass-legume	0.5	5 [1.5]	4 [1.2]
Mixture	5-10	4 [1.2]	3 [0.9]
Red fescue	0.5	3 [0.9]	2.5 [0.8]
Redtop	5-10	Not recommended	Not recommended

\*Adapted from Chow (1959), Livingston et al. (1984), and Goldman et al. (1986).

**SC-4.** Select a trial Manning's n. The minimum value for poor vegetation cover and low height (possibly, knocked from the vertical by high flow) is 0.033. A good initial choice under these conditions is 0.04.

**SC-5.** Refer to Figure 9.6 to obtain a first approximation for VR.



Note: VR is the product of velocity and hydraulic radius

Figure 9.6 The Relationship of Manning's n with VR for Various Degrees of Flow Retardance (A-E)

Source: Livingston, et al, 1984

**SC-6.** Compute hydraulic radius,  $R$ , from  $VR$  in Figure 9.6 and  $V_{max}$  in Table 9.3.

**SC-7.** Use Manning's equation to solve for the actual  $VR$ .

**SC-8.** Compare the actual  $VR$  from step SC-7 and first approximation from step SC-5. If they do not agree within 5 percent, repeat steps SC-4 to SC-8 until acceptable agreement is reached. If  $n < 0.033$  is needed to get agreement, set  $n = 0.033$ , repeat step SC-7, and then proceed to step SC-9.

**SC-9.** Compute the actual  $V$  for the final design conditions:

Check to be sure  $V < V_{max}$

**SC-10.** Compute the required swale cross-sectional area,  $A$ , for stability:

**SC-11.** Compare the  $A$ , computed in step SC-10 of the stability analysis, with the  $A$  from the biofiltration capacity analysis (step D-5).

If less area is required for stability than is provided for capacity, the capacity design is acceptable. If not, use  $A$  from step SC-10 of the stability analysis and recalculate channel dimensions.

**SC-12.** Calculate the depth of flow at the stability check design flow rate condition for the final dimensions and use  $A$  from step SC-10.

**SC-13.** Compare the depth from step SC-12 to the depth used in the biofiltration capacity design (Step D-1). Use the larger of the two and add 0.5 ft. of freeboard to obtain the total depth ( $y_t$ ) of the swale. Calculate the top width for the full depth using the appropriate equation.

**SC-14.** Recalculate the hydraulic radius: (use  $b$  from Step D-4 calculated previously for biofiltration capacity, or Step SC-11, as appropriate, and  $y_t$  = total depth from Step SC-13)

**SC-15.** Make a final check for capacity based on the stability check design storm (this check will ensure that capacity is adequate if the largest expected event coincides with the greatest retardance). Use Equation 1, a Manning's  $n$  selected in step D-2, and the calculated channel dimensions, including freeboard, to compute the flow capacity of the channel under these conditions. Use  $R$  from step SC-14, above, and  $A = b(y_t) + Z(y_t)^2$  using  $b$  from Step D-4, D-15, or SC-11 as appropriate.

If the flow capacity is less than the stability check design storm flow rate, increase the channel cross-sectional area as needed for this conveyance. Specify the new channel dimensions.

#### ***Completion Step (CO)***

**CO.** Review all of the criteria and guidelines for biofilter planning, design, installation, and operation above and specify all of the appropriate features for the application.

### *Example of Design Calculations for Biofiltration Swales*

#### *Preliminary Steps*

**P-1.** Assume that the WWHM based Water Quality Design Flow Rate in 15 minute time-steps, Q, is 0.2 cfs. *Assume an on-line facility.*

**P-2.** Assume the slope (s) is 2 percent.

**P-3.** Assume the vegetation will be a grass-legume mixture and it will be infrequently mowed.

#### *Design for Biofiltration Swale Capacity*

**D-1.** Set winter grass height at 5" and the design flow depth (y) at 3 inches.

**D-2.** Use  $n = 0.20$  to  $n_2 = 0.30$

**D-3.** Base the design on a trapezoidal shape, with a side slope  $Z = 3$ .

**D-4a.** Calculate the bottom width, b;

Where:

$$n = 0.20 \quad y = 0.25 \text{ ft}$$

$$Q = 0.2 \text{ cfs} \quad s = 0.02$$

$$Z = 3$$

$$b \approx \frac{2.5Qn}{1.49y^{1.67}s^{0.5}} - Zy$$

$$b \approx 4.0 \text{ ft}$$

$$\text{At } n_2; b_2 = 6.5 \text{ feet}$$

**D-4b.** Calculate the top width (T)

$$T = b + 2yZ = 4.0 + [2(0.25)(3)] = 5.5 \text{ feet}$$

**D-5.** Calculate the cross-sectional area (A)

$$A = by + Zy^2 = (4.0)(0.25) + (3)(0.25^2) = 1.19 \text{ ft}^2$$

**D-6.** Calculate the flow velocity (V)

$$V = K \frac{Q}{A} = 0.17 \text{ ft} / \text{sec}$$

*for  $K = 1$ . Actual  $K$  is determined per Figure 9.5a*

$$0.17 < 1.0 \text{ ft/sec} \therefore \text{OK}$$

**D-7 Calculate the Length (L)**

$$L = Vt(60 \text{ sec/min})$$

$$= 0.17 (229)(60)$$

For  $t = 229$  min,  $L = 22492$  ft. at  $n$ ; *expand to a minimum of 100 foot length per design criterion*

$$\text{At } n_2; L = 145 \text{ } 100 \text{ ft.}$$

*Because Note: Where  $b$  is less than the maximum value, it may be possible to reduce  $L$  by increasing  $b$ . In this case, because  $L$  is determined by the requirement for a minimum length of 100 feet, it is not possible. For example, if  $L = 180$  ft is desired at  $n$ , then:*

$$V = \frac{L}{60t} = 0.136 \text{ ft/sec}$$

$$A = \frac{Q}{V} = 1.47 \text{ ft}^2$$

$$b = \frac{A - Zy^2}{y} = 5.13 \text{ ft at } n;$$

$$\text{At } n_2 \text{ and } L = 130 \text{ feet; } b_2 = 7.41 \text{ ft.}$$

*Note:  $b$  and  $L$  are calculated at the same flow.*

**Check for Channel Stability**

*Note: The numbers in this example have not been updated for the new design condition.*

**SC-1.** Base the check on passing the 100-year, return frequency flow (15 minute time steps) through a swale with a mixture of Kentucky bluegrass and tall fescue on loose erodible soil. Until WWHM peak flow rates in 15-minute time steps are available the designer can use the WWHM 100-yr. hourly peak flows times an adjustment factor of 1.6 to approximate peak flows in 15-minute time steps. Assume that the adjusted peak  $Q$  is 1.92 cfs.

**SC-2.** Base the check on a grass height of 3 inches with "fair" coverage (lowest mowed height and least cover, assuming flow bypasses or does not occur during grass establishment).

**SC-3.** From Table 9.2, Degree of Retardance = D (low)

From Table 9.3 set  $V_{\max} = 5 \text{ ft/sec}$



**SC-4.** Select trial Manning's  $n = 0.04$

**SC-5.** From Figure 9.6,  $VR_{\text{appx}} = 3 \text{ ft}^2/\text{s}$

**SC-6.** Calculate  $R$

$$R = \frac{VR_{\text{appx}}}{V_{\text{max}}} = 0.6 \text{ ft}$$

**SC-7.** Calculate  $VR_{\text{actual}}$

$$VR_{\text{actual}} = \frac{1.49}{n} R^{1.67} s^{0.5} = 2.24 \text{ ft}^2 / \text{sec}$$

**SC-8.**  $VR_{\text{actual}}$  from step SC-7 <  $VR_{\text{appx}}$  from step SC-5 by > 5%.

Select new trial  $n = 0.038$

Figure 9.6:  $VR_{\text{appx}} = 4 \text{ ft}^2/\text{s}$

$R = 0.8 \text{ ft}$ .

$VR_{\text{actual}} = 3.81 \text{ ft}^2/\text{s}$  (within 5% of  $VR_{\text{appx}} = 4$ )

**SC-9.** Calculate  $V$

$$V = \frac{VR_{\text{actual}}}{R} = \frac{3.81}{0.8} = 4.76 \text{ ft / sec}$$

$V = 4.76 \text{ ft/sec} < 5 \text{ ft/sec} \therefore \text{OK}$

**SC-10.** Calculate Stability Area

$$A_{\text{Stability}} = \frac{Q}{V} = \frac{1.92}{4.76} = 0.4 \text{ ft}^2$$

**SC-11.** Stability Check

$A_{\text{Stability}} = 0.4 \text{ ft}^2$  is less than  $A_{\text{Capacity}}$  from step D-5 ( $A_{\text{Capacity}} = 1.19 \text{ ft}^2$ ) or D-7 ( $A_{\text{Capacity}} = 1.47 \text{ ft}^2$ ).  $\therefore \text{OK}$

At  $n_2$  and  $b_2$ :  $A_{\text{capacity}} = 1.81 \text{ ft}^2$  from D-5, and  $A_{\text{capacity}} = 2.04 \text{ ft}^2$  from D-7:  $\therefore \text{OK}$

If  $A_{\text{Stability}} > A_{\text{Capacity}}$ , it will be necessary to select new trial sizes for width and flow depth (based on space and other considerations), recalculate  $A_{\text{Capacity}}$ , and repeat steps SC-10 and SC-11.

**SC-12.** Calculate depth of flow at the stability design flow rate condition using the quadratic equation solution:

$$y = \frac{-b \pm \sqrt{b^2 - 4Z(-A)}}{2Z}$$

For  $b = 5.13$ ,  $y = 0.075$  ft (positive root)

**SC-13.** Greater depth is 0.25-foot, which was the basis for the biofiltration capacity design. Add 0.05 feet freeboard to that depth.

Total channel depth = 0.75 ft

Top Width =  $b + 2yZ$

=  $5.13 + (2)(0.75)(3)$

= 9.63 ft

**SC-14.** Recalculate hydraulic radius and flow rate

For  $b = 5.13$  ft,  $y = 0.75$  ft

$Z = 3$ ,  $s = 0.02$ ,  $n = 0.2$

$A = by + Zy^2 = 5.54$  ft<sup>2</sup>

$R = by + Zy^2 / \{b + 2y\sqrt{Z^2 + 1}\} = 0.56$  ft.

**SC-15.** Calculate Flow Capacity at Greatest Resistance

$$Q = \frac{1.49AR^{0.67}s^{0.5}}{n} = 3.9 \text{ cfs}$$

$Q = 3.9$  cfs > 1.6 cfs  $\therefore$  OK

At  $n_2$  and  $b_2$ :  $Q = 3.7$  cfs  $\therefore$  OK

### ***Completion Step***

**CO-1.** Assume 180 feet of swale length is available.

The final channel dimensions are:

Bottom width,  $b = 5.13$  feet

Channel depth = 0.75 feet

Top width =  $b + 2yZ = 9.63$  feet

**CO-2.** At swale length of 130 feet and  $n_2$ :

Bottom width,  $b_2 = 7.41$  feet

Channel depth = 0.75 feet

Top width =  $b_2 + 2yZ = 11.91$  feet

No check dams are needed for a 2% slope.

### ***Soil Criteria***

- The following top soil mix at least 8-inch deep:
  - Sandy loam 60-90 %
  - Clay 0-10 %
  - Composted organic matter, 10-30 %  
(excluding animal waste, toxics)

- Use compost amended soil where practicable
- Till to at least 8-inch depth
- For longitudinal slopes of < 2 percent use more sand to obtain more infiltration
- If ground water contamination is a concern, seal the bed with clay or a geomembrane liner

#### ***Vegetation Criteria***

- See Tables 9.4, 9.5 and 9.6 for recommended grasses, wetland plants, and groundcovers.
- Select fine, turf-forming, water-resistant grasses where vegetative growth and moisture will be adequate for growth.
- Irrigate if moisture is insufficient during dry weather season.
- Use sod with low clay content and where needed to initiate adequate vegetative growth. Preferably sod should be laid to a minimum of one-foot vertical depth above the swale bottom.
- Consider sun/shade conditions for adequate vegetative growth and avoid prolonged shading of any portion not planted with shade tolerant vegetation.
- Stabilize soil areas upslope of the biofilter to prevent erosion
- Fertilizing a biofilter should be avoided if at all possible in any application where nutrient control is an objective. Test the soil for nitrogen, phosphorous, and potassium and consult with a landscape professional about the need for fertilizer in relation to soil nutrition and vegetation requirements. If use of a fertilizer cannot be avoided, use a slow-release fertilizer formulation in the least amount needed.

#### ***Recommended grasses (see Tables 9.4 and 9.5 below)***

<b>Table 9.4 -- Grass seed mixes suitable for biofiltration swale treatment areas</b>			
<b>Mix 1</b>		<b>Mix 2</b>	
75-80 percent	tall or meadow fescue	60-70 percent	tall fescue
10-15 percent	seaside/colonial bentgrass	10-15 percent	seaside/colonial bentgrass
5-10 percent	redtop	10-15 percent	meadow foxtail
		6-10 percent	alsike clover
		1-5 percent	marshfield big trefoil
		1-6 percent	redtop

Note: all percentages are by weight. \* based on Briargreen, Inc.

Table 9.5 -- Groundcovers and grasses suitable for the upper side slopes of a biofiltration swale in western Washington	
<b>Groundcovers</b>	
kinnikinnick*	<i>Arctostaphylos uva-ursi</i>
St. John's-wort	<i>Hypericum perforatum</i>
Epimedium	<i>Epimedium grandiflorum</i>
creeping forget-me-not	<i>Omphalodes verna</i>
--	<i>Euonymus lanceolata</i>
yellow-root	<i>Xanthorhiza simplissima</i>
--	<i>Genista</i>
white lawn clover	<i>Trifolium repens</i>
white sweet clover*	<i>Melilotus alba</i>
-----	<i>Rubus calycinoides</i>
strawberry*	<i>Fragaria chiloensis</i>
broadleaf lupine*	<i>Lupinus latifolius</i>
<b>Grasses (drought-tolerant, minimum mowing)</b>	
dwarf tall fescues	<i>Festuca</i> spp. (e.g., Many Mustang, Silverado)
hard fescue	<i>Festuca ovina duriuscula</i> (e.g., Reliant, Aurora)
tufted fescue	<i>Festuca amethystinae</i>
buffalo grass	<i>Buchloe dactyloides</i>
red fescue*	<i>Festuca rubra</i>
tall fescue grass*	<i>Festuca arundinacea</i>
blue oatgrass	<i>Helictotrichon sempervirens</i>

### Construction Criteria

The biofiltration swale should not be put into operation until areas of exposed soil in the contributing drainage catchment have been sufficiently stabilized. Deposition of eroded soils can impede the growth of grass in the swale and reduce swale treatment effectiveness. Thus, effective erosion and sediment control measures should remain in place until the swale vegetation is established (see Volume II for erosion and sediment control BMPs). Avoid compaction during construction. Grade biofilters to attain uniform longitudinal and lateral slopes

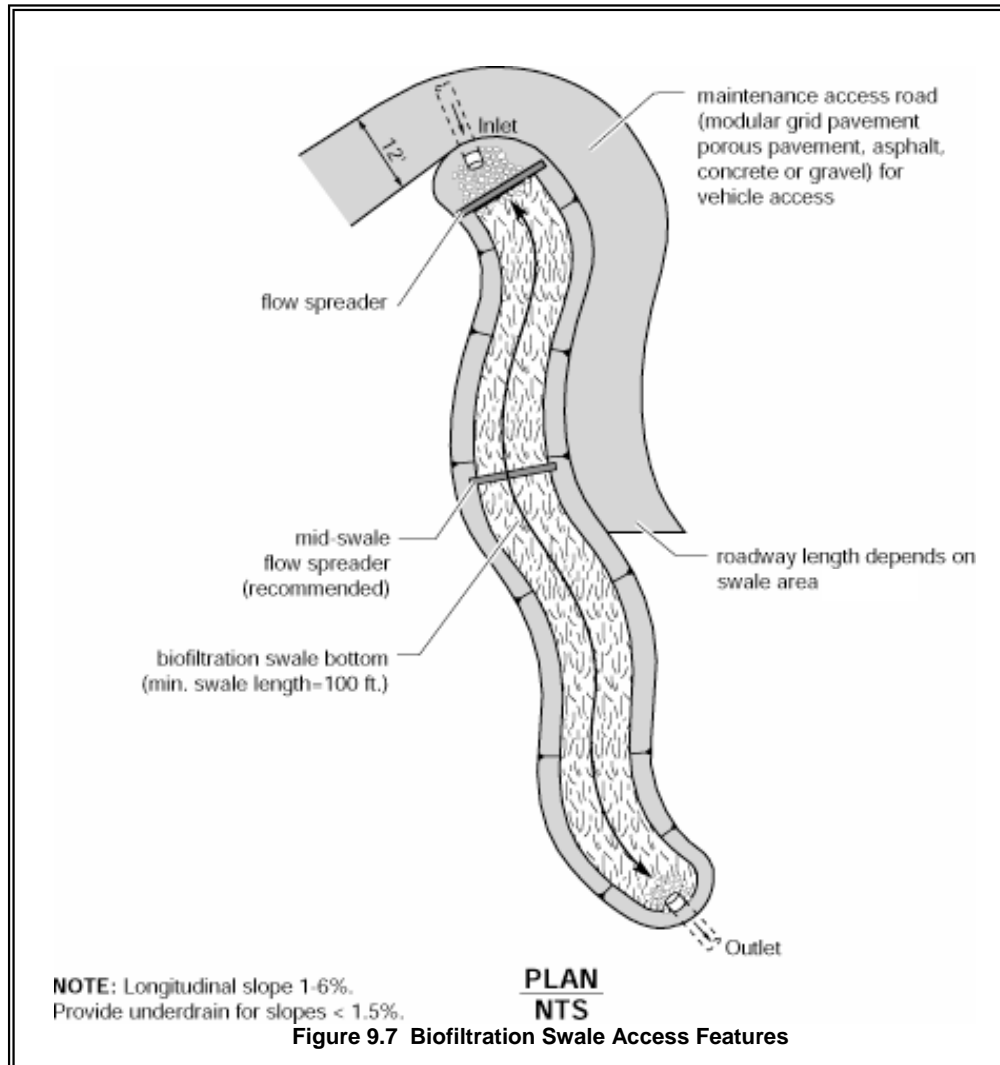
### Maintenance Criteria

- Inspect biofilters at least once every 6 months, preferably during storm events, and also after storm events of > 0.5 inch rainfall/ 24 hours. Maintain adequate grass growth and eliminate bare spots.
- Mow grasses, if needed for good growth {typically maintain at 4 – 9 inches and not below design flow level (King County, 1998)}.
- Remove sediment as needed at head of the swale if grass growth is inhibited in greater than 10 percent of the swale, or if the sediment is blocking the distribution and entry of the water (King County, 1998).
- Remove leaves, litter, and oily materials, and re-seed or resod, and regrade, as needed. Clean curb cuts and level spreaders as needed.

Prevent scouring and soil erosion in the biofilter. If flow channeling occurs, regrade and reseed the biofilter, as necessary.

Maintain access to biofilter inlet, outlet, and to mowing (Figure 9.7)

- If a swale is equipped with underdrains, vehicular traffic on the swale bottom (other than grass mowing equipment) should be avoided to prevent damage to the drainpipes.



## BMP T9.20 Wet Biofiltration Swale

### *Description*

A *wet biofiltration swale* is a variation of a basic biofiltration swale for use where the longitudinal slope is slight, water tables are high, or continuous low base flow is likely to result in saturated soil conditions. Where saturation exceeds about 2 weeks, typical grasses will die. Thus, vegetation specifically adapted to saturated soil conditions is needed. Different vegetation in turn requires modification of several of the design parameters for the basic biofiltration swale.

### *Performance Objectives*

To remove low concentrations of pollutants such as TSS, heavy metals, nutrients, and petroleum hydrocarbons.

### *Applications/Limitations*

Wet biofiltration swales are applied where a basic biofiltration swale is desired but not allowed or advisable because one or more of the following conditions exist:

- The swale is on till soils and is downstream of a detention pond providing flow control.
- Saturated soil conditions are likely because of seeps or base flows on the site.
- Longitudinal slopes are slight (generally less than 2 percent).

### *Design Criteria*

Use the same design approach as for basic biofiltration swales except to add the following:

**Adjust for extended wet season flow.** If the swale will be downstream of a detention pond providing flow control, multiply the treatment area (bottom width times length) of the swale by 2, and readjust the swale length, if desired. Maintain a 5:1 length to width ratio.

**Intent:** An increase in the treatment area of swales following detention ponds is required because of the differences in vegetation established in a constant flow environment. Flows following detention are much more prolonged. These prolonged flows result in more stream-like conditions than are typical for other wet biofilter situations. Since vegetation growing in streams is often less dense, this increase in treatment area is needed to ensure that equivalent pollutant removal is achieved in extended flow situations.

**Swale Geometry:** Same as specified for basic biofiltration swales except for the following modifications:

**Criterion 1:** The bottom width may be increased to 25 feet maximum, but a length-to-width ratio of 5:1 must be provided. No longitudinal dividing berm is needed. *Note: The minimum swale length is still 100 feet.*

**Criterion 2:** If longitudinal slopes are greater than 2 percent, the wet swale must be stepped so that the slope within the stepped sections averages 2 percent. Steps may be made of retaining walls, log check dams, or short riprap sections. **No underdrain or low-flow drain is required.**

**High-Flow Bypass:** A high-flow bypass (*i.e., an off-line design*) is required for flows greater than the *off-line* water quality design flow *that has been increased by the ratio indicated in Figure 9.5b. The bypass is necessary* to protect wetland vegetation from damage. Unlike grass, wetland vegetation will not quickly regain an upright attitude after being laid down by high flows. New growth, usually from the base of the plant, often taking several weeks, is required to regain its upright form. The bypass may be an open channel parallel to the wet biofiltration swale. *(NOTE: Local governments may continue to require 2.5 times the new water quality design flow rate to be directed through off-line wet biofiltration swales. See “Guidance for Bypassing Off-line Facilities” under BMP T 9.10—Basic Biofiltration Swales.)*

**Water Depth and Base Flow:** Same as for basic biofiltration swales except the design water depth shall be 4 inches for all wetland vegetation selections, and **no underdrains or low-flow drains are required.**

**Flow Velocity, Energy Dissipation, and Flow Spreading:** Same as for basic biofiltration swales except no flow spreader is needed.

**Access:** Same as for basic biofiltration swales except access is only required to the inflow and the outflow of the swale; access along the length of the swale is not required. Also, wheel strips may not be used for access in the swale.

**Intent:** An access road is not required along the length of a wet swale because of infrequent access needs. Frequent mowing or harvesting is not desirable. In addition, wetland plants are fairly resilient to sediment-induced changes in water depth, so the need for access should be infrequent.

**Soil Amendment:** Same as for basic biofiltration swales.

**Planting Requirements:** Same as for basic biofiltration swales except for the following modifications:

1. A list of acceptable plants and recommended spacing is shown in Table 9.6. In general, it is best to plant several species to increase the likelihood that at least some of the selected species will find growing conditions favorable.
2. A wetland seed mix may be applied by hydroseeding, but if coverage is poor, planting of rootstock or nursery stock is required. Poor coverage is considered to be more than 30 percent bare area through the upper 2/3 of the swale after four weeks.

**Recommended Design Features:** Same as for basic biofiltration swales

**Construction Considerations:** Same as for basic biofiltration swales

**Maintenance Considerations:** Same as for basic biofiltration swales except mowing of wetland vegetation is not required. However, harvesting of very dense vegetation may be desirable in the fall after plant die-back to prevent the sloughing of excess organic material into receiving waters. Many native *Juncus* species remain green throughout the winter; therefore, fall harvesting of *Juncus* species is not recommended.

<b>Table 9.6 Recommended plants for wet biofiltration swale</b>		
<b>Common Name</b>	<b>Scientific Name</b>	<b>Spacing (on center)</b>
Shortawn foxtail	<i>Alopecurus aequalis</i>	seed
Water foxtail	<i>Alopecurus geniculatus</i>	seed
Spike rush	<i>Eleocharis spp.</i>	4 inches
Slough sedge*	<i>Carex obnupta</i>	6 inches or seed
Sawbeak sedge	<i>Carex stipata</i>	6 inches
Sedge	<i>Carex spp.</i>	6 inches
Western mannagrass	<i>Glyceria occidentalis</i>	seed
Velvetgrass	<i>Holcus mollis</i>	seed
Slender rush	<i>Juncus tenuis</i>	6 inches
Watercress*	<i>Rorippa nasturtium-aquaticum</i>	12 inches
Water parsley*	<i>Oenanthe sarmentosa</i>	6 inches
Hardstem bulrush	<i>Scirpus acutus</i>	6 inches
Small-fruited bulrush	<i>Scirpus microcarpus</i>	12 inches

\* Good choices for swales with significant periods of flow, such as those downstream of a detention facility.

Note: Cattail (*Typha latifolia*) is not appropriate for most wet swales because of its very dense and clumping growth habit which prevents water from filtering through the clump.



## BMP T9.30 Continuous Inflow Biofiltration Swale

### *Description*

In situations where water enters a biofiltration swale continuously along the side slope rather than discretely at the head, a different design approach—the continuous inflow biofiltration swale—is needed. The basic swale design is modified by increasing swale length to achieve an equivalent average residence time.

### *Applications*

A continuous inflow biofiltration swale is to be **used when inflows are not concentrated**, such as locations along the shoulder of a road without curbs. This design may also be **used where frequent, small point flows enter a swale**, such as through curb inlet ports spaced at intervals along a road, or from a parking lot with frequent curb cuts. In general, no inlet port should carry more than about 10 percent of the flow.

A continuous inflow swale is not appropriate for a situation in which significant lateral flows enter a swale at some point downstream from the head of the swale. In this situation, the swale width and length must be recalculated from the point of confluence to the discharge point in order to provide adequate treatment for the increased flows.

### *Design Criteria*

Same as specified for **basic biofiltration swale** except for the following:

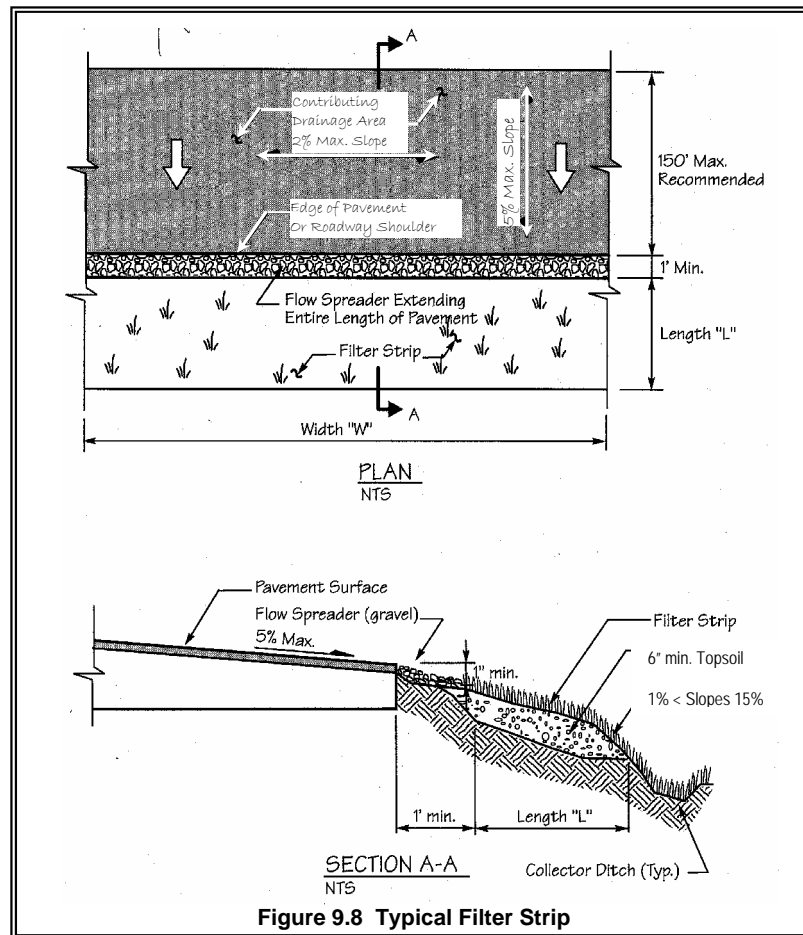
- The design flow for continuous inflow swales must include runoff from the pervious side slopes draining to the swale along the entire swale length. *Therefore, they must be on-line facilities.*
- If only a single design flow is used, the flow rate at the outlet should be used. The goal is to achieve an average residence time through the swale of *229* minutes *as calculated using the on-line water quality design flow rate multiplied by the ratio, K, in Figure 9.5a*. Assuming an even distribution of inflow into the side of the swale double the hydraulic residence time to a minimum of *4418* minutes.
- For continuous inflow biofiltration swales, interior side slopes above the WQ design treatment elevation shall be planted in grass. A typical lawn seed mix or the biofiltration seed mixes are acceptable. Landscape plants or groundcovers other than grass may not be used anywhere between the runoff inflow elevation and the bottom of the swale.

**Intent:** The use of grass on interior side slopes reduces the chance of soil erosion and transfer of pollutants from landscape areas to the biofiltration treatment area.

## BMP T9.40 Basic Filter Strip

### Description:

A basic filter strip is flat with no side slopes (Figure 9.8). Contaminated stormwater is distributed as sheet flow across the inlet width of a biofilter strip.



### Applications/Limitations:

The basic filter strip is typically used on-line and adjacent and parallel to a paved area such as parking lots, driveways, and roadways.

**Design Criteria for Filter strips:**

- Use the Design Criteria specified in Table 9.3
- Filter strips should only receive sheet flow.
- Use curb cuts  $\geq$  12-inch wide and 1-inch above the filter strip inlet.

Calculate the design flow depth using Manning's equation as follows:

$$KQ = (1.49A R^{0.67} s^{0.5})/n$$

Substituting for AR:

$$KQ = (1.49Ty^{1.67} s^{0.5})/n$$

Where:

$$Ty = A_{\text{rectangle, ft}}^2$$

y  $\approx$  R<sub>rectangle</sub>, design depth of flow, ft. (1 inch maximum)

Q = peak Water Quality design flow rate based on WWHM, ft<sup>3</sup>/sec  
(See Appendix I-B, Volume I)

K = The ratio determined by using Figure 9.5a

n = Manning's roughness coefficient

s = Longitudinal slope of filter strip parallel to direction of flow

T = Width of filter strip perpendicular to the direction of flow, ft.

A = Filter strip inlet cross-sectional flow area (rectangular), ft<sup>2</sup>

R = hydraulic radius, ft.

Rearranging for y:

$$y = [2.5KQn/1.49Ts^{0.5}]^{0.6}$$

y must not exceed 1 inch

*Note: As in swale design an adjustment factor of ~~2.5~~ K accounts for the differential between the WWHM Water Quality design flow rate and the SBUH design flow*

Calculate the design flow velocity V, ft./sec., through the filter strip:

$$V = KQ/Ty$$

V must not exceed 0.5 ft./sec

Calculate required length, ft., of the filter strip at the minimum hydraulic residence time, t, of 229 minutes:

$$L = tV = 5401320/V$$

## BMP T9.50 Narrow Area Filter Strip

### *Description:*

This section describes a filter strip design<sup>1</sup> for impervious areas with flowpaths of 30 feet or less that can drain along their widest dimension to grassy areas.

### *Applications/Limitations:*

A narrow area filter strip could be used at roadways with limited right-of-way, or for narrow parking strips, the narrow strip. If space is available to use the basic filter strip design, that design should be used in preference to the narrow filter strip.

The treatment objectives, applications and limitations, design criteria, materials specifications, and construction and maintenance requirements set forth in the basic filter strip design apply to narrow filter strip applications.

### *Design Criteria:*

Design criteria for narrow area filter strips are the *same as specified for basic filter strips*. The sizing of a narrow area filter strip is based on the length of flowpath draining to the filter strip and the longitudinal slope of the filter strip itself (parallel to the flowpath).

*Step 1:* Determine the length of the flowpath from the upstream to the downstream edge of the impervious area draining sheet flow to the strip. Normally this is the same as the width of the paved area, but if the site is sloped, the flow path may be longer than the width of the impervious area.

*Step 2:* Calculate the longitudinal slope of the filter strip (along the direction of unconcentrated flow), averaged over the total width of the filter strip. The minimum sizing slope is 2 percent. If the slope is less than 2 percent, use 2 percent for sizing purposes. The maximum allowable filter strip slope is 20 percent. If the slope exceeds 20 percent, the filter strip must be stepped down the slope so that the treatment areas between drop sections do not have a longitudinal slope greater than 20 percent. Drop sections must be provided with erosion protection at the base and flow spreaders to re-spread flows.

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<sup>1</sup> This narrow area filter strip design method is included here because technical limitations exist in the basic design method which result in filter strips that are proportionately longer as the contributing drainage becomes narrower (a result that is counter-intuitive). Research by several parties is underway to evaluate filter strip design parameters. This research may lead to more stringent design requirements that would supersede the design criteria presented here.

Vertical drops along the slope must not exceed 12 inches in height. If this is not possible, a different treatment facility must be selected.

*Step 3:* Select the appropriate filter strip length for the flowpath length and filter strip longitudinal slope (Steps 1 and 2 above) from the graph in Figure 9.9. The filter strip must be designed to provide this minimum length *L* along the entire stretch of pavement draining into it.

*To use the graph:* Find the length of the flowpath on one of the curves (interpolate between curves as necessary). Move along the curve to the point where the design longitudinal slope of the filter strip (x-axis) is directly below. Read the filter strip length on the y-axis which corresponds to the intersection point.

